TEACHING SUPPLY CHAIN MANAGEMENT STUDENTS ABOUT USING ACTUAL MOTOR CARRIER FREIGHT RATES IN PURCHASE LOT-SIZING MODELS

Michael Godfrey, University of Wisconsin Oshkosh
Andrew Manikas, University of Wisconsin Oshkosh

ABSTRACT

In this paper, we analyze a purchase lot-sizing decision that includes transport cost using actual motor carrier freight rates. Lot-sizing models in the literature either estimate motor carrier freight rates with a continuous function or simplify less-than-truckload freight rates unrealistically by using too few weight-break ranges. We present an Excel Solver model that we use in a supply chain management class to teach students the following principles: how to look up less-than-truckload freight rates using a carrier's software, how to calculate less-than-truckload and truckload freight rates, to decide whether to over-declare (artificially inflate) the weight of a less-than-truckload shipment to lower the freight charge, and how to find the purchase lot size that minimizes annual logistics cost. We assume that all-units purchase quantity discounts are offered by the supplier and the product is shipped Free On Board (FOB) Origin, Freight Collect. We discuss how to solve this model with Excel's GRG Nonlinear Solver.

JEL: A22, C61, C88, N72

KEYWORDS: Excel Solver, linear programming, logistics, purchase lot-sizing

INTRODUCTION

Total annual logistics cost models were been discussed in the literature around 1970 (e.g., Baumol and Vinod, 1970). These "inventory-theoretic" models add transportation costs to the economic order quantity (EOQ) model, resulting in a model that combines transport, order, holding, and purchase costs. The inventory theoretic model in this paper has been used in an exercise in our supply chain management courses. We have used this model to teach students how to perform the following: (a) to look up less-than-truckload (LTL) freight rates using software from an LTL carrier; (b) to calculate LTL and truckload (TL) freight rates; (c) to decide whether to over-declare the weight of an LTL shipment to lower the total freight charge, and (d) to find the purchase lot size that minimizes annual logistics cost. Annual logistics cost equals the total of annual order cost, annual warehouse holding cost, annual in-transit holding cost, annual transportation cost, and annual purchase cost. In the next section, we review the literature discussing inventory-theoretic models. Next, we present the methodology: the data and the Excel spreadsheet and Solver model. Next, we report and discuss the results from this exercise. The last section is the conclusion section.

LITERATURE REVIEW

Baumol and Vinod (1970) introduced the inventory-theoretic model. Later, other researchers (e.g., Carter & Ferrin, 1996; Gaither, 1982; Langley, 1980; Larson, 1988; Tyworth, 1991b; Wehrman, 1984) demonstrated adding actual motor carrier freight rates to the purchase lot-sizing decision by using enumeration techniques. Other researchers, e.g., Burwell, Dave, Fitzpatrick, & Roy, 1997; Hwan, Moon, & Shin, 1990; Lee, 1986; Madadi, Kurz, & Ashayeri, 2010; Ramasesh, 1993; Russell & Krajewski, 1991; Tersine & Barman, 1991; Tersine, Larson, & Barman, 1989, created complex algorithms to add actual freight rates into the purchase lot-sizing decision. More recently, Mendoza and Ventura (2008) presented an algorithm based on a grossly simplified freight rate structure (using either a constant charge per truckload (TL) or a constant cost per unit for less-than-truckload (LTL) shipments). Their algorithm also included two types of purchase quantity discounts (all-units and incremental). He, Hu, and Guo (2010) explained an algorithm for finding the optimal purchase quantity using actual freight rates; however, their model did not incorporate purchase quantity discounts.

The difficulty in solving the inventory-theoretic model when using actual motor carrier freight rates is created by the complexity of the LTL freight rates. This complexity is caused by the practice of over-declaring LTL shipments (this issue is discussed later in this paper). Given this complexity, researchers resorted to using enumeration techniques or complex algorithms when using actual freight rates. Alternatively, other researchers decided to model freight rates with continuous functions as described next.Modeling freight rates is estimating freight rates based on the value of some parameter in a continuous function. Examples of these parameters include: (a) the TL charge in an inverse function (Blumenfeld, Burns, Daganzo, Frick, & Hall, 1987; Sheffi, Eskandari, & Koutsopoulos, 1988; Swenseth & Godfrey, 2002; Yildirmaz, Karabati, & Sayin, 2009); (b) distance in a proportional function (Ballou, 1991); (c) the constant used as an exponent in an exponential function (Buffa, 1987, 1988); (d) the smoothing constant in an adjusted inverse function (Swenseth & Buffa, 1990, 1991; Swenseth & Godfrey, 1996; Swenseth & Godfrey, 2002); and (e) load density, shipment weight, and shipment distance in a nonlinear model (Kay & Warsing, 2009). Ballou (1991) argued that considerations such as time, effort, and cost often dictate that logistics decision-makers should use estimated, rather than actual, freight rates.

Mendoza and Ventura (2009) described several limitations when trying to use actual freight rates: time and expense determining exact rates between origin and destination and the issue of the freight rate function not being differentiable. Time, effort, and cost would be expended searching for LTL freight rates for all possible weight-break ranges, determining over-declared weights for each LTL weight-break range, and enumerating all possible lot-size alternatives. In addition, Kay and Warsing (2009) argued that representing the freight rates with an equation makes it easy to determine the optimal purchase lot size, and that shippers would be able to avoid paying for access to LTL tariffs. Using freight rate functions, however, leads to another problem. Tyworth (1991a) and Higginson (1993) criticized existing freight rate functions for not estimating freight rates accurately. Besides, LTL freight rate software can be downloaded at no cost from many LTL carriers. In addition, the minimum cost purchase lot size can be determined with a basic Excel Solver model that uses actual LTL and TL freight rates.

METHODOLOGY

Data

The inventory-theoretic model presented here uses the data shown in Table 1 (copied from the Excel spreadsheet). The instructor provides students the data for a single purchased item that is shipped Free On Board (FOB) Origin, Freight Collect. We assume the buyer arranges transportation, pays the carrier, and bears the freight charges. In addition, the supplier offers all-units purchase quantity discounts. Table 1 displays part of the Excel spreadsheet used for entering data. The instructor provides students most of the data except for the less-than-truckload (LTL) freight rates, which the students must find using ABF's Q-Rate for Windows ® (Q-Rate Download). Students must enter the following data for the problem on the left part of the screen: Holding Cost Rate Warehouse (Cell C7), Holding Cost Rate In-transit (Cell C10), Annual Demand in units (Cell C12), Order Cost (Cell C14), Unit Weight in pounds (Cell C16), Unit Cube in cubic feet (Cell C17), Freight Class (Cell C18), Less-than-Truckload (LTL) Shipping Time Days (Cell C22), Truckload (TL) Shipping Time Days (Cell C23), Maximum TL Weight in pounds (Cell C25), and Maximum TL Cube (Cell C27). The Maximum TL weight is based on a trailer loaded exactly at the U.S. gross weight limit of 80,000 pounds. Similarly, the TL cube is based on the maximum cubic capacity of a 53-foot trailer. We caution students that companies will create guidelines for limits on weight and cube limits for different products based on their unique product characteristics and transport equipment.

Table 1: Input Screen

	B	C	D	E	F	G
5	**Origin Zip Code:**	19140		**Destination Zip Code:**	54901	
6	**Inputs:**			**Unit Cost Schedule**		
7	Holding Cost Rate	0.65		At Least	Unit Cost	
8	at Warehouse			1	$195.00	
9				300	$194.90	
10	Holding Cost Rate	0.45		600	$194.80	
11	In-transit					
12	Annual Demand	5,000		**Nominal Freight Rate Schedule**		
13				**Range**	**Rate**	
14	Order Cost	$42.00		Minimum LTL Charge	$367.79	
15				1	$234.46	/CWT
16	Unit Weight	40.00		500	$196.36	/CWT
17	Unit Cube	4.50		1000	$164.00	/CWT
18	Freight Class	100		2000	$145.50	/CWT
19				5000	$115.89	/CWT
20				10000	$104.30	/CWT
21	Shipping Time (days)			20000	$93.87	/CWT
22	(LTL)	3		LTL Discount (%)	60.00%	
23	(TL)	2		LTL Fuel Surcharge (%)	30.50%	
24						
25	Max.TL Weight	46,100				
26	(Pounds)			TL Fuel Surcharge/Mile	$0.64	/MILE
27	Max. TL Cube	3,936		TL RATE/MILE ($)	$0.97	/MILE
28				MILES	909	
29				Min. TL CHARGE	$600.00	

This table shows all of the data that a student must enter for this purchased item, including holding cost rates, order costs, shipment characteristics, shipping times, trailer capacities, purchase costs, and freight charges.

On the right of the screen are data related to purchase costs and transportation costs. The all-units purchase quantity discount schedule is listed in a table array named, “UnitCostLookup” (Cells E8:F11). This array is created as follows: (a) Highlight Cells E8:F11, (b) Select “Formulas” from the Excel toolbar, (c) Select “Define Name” from “Name Manager,” enter the name, “UnitCostLookup,” and select “OK.” This table array can be searched using the “VLOOKUP” function of Excel to find the purchase cost per unit for a given order quantity. The problem considered here has three purchase quantity ranges: 1 – 299 units, 300 – 599 units, and 600+ units. The LTL freight rates (Cells F14:F21) are nominal freight rates (no LTL discount has been applied) and are available on Q-Rate for Windows ®.

The instructions for retrieving LTL freight rates from this software are as follows: (1) Download and install Q-Rate for Windows ®, (2) Enter the origin zip code and the destination zip code, (3) Uncheck “Single shipment charge,” (4) Left click on “Tools,” (5) Left click on “Rate Inquiry,” (6) Print the nominal tariff of LTL freight charges. This tariff lists nominal freight rates for all freight classes (based mainly on product density) and weight-break ranges. Once students have printed the tariff of nominal freight rates, they must find the row for the given freight class (Class 100 was used in this exercise) and the matching freight rates. Then, students must enter those freight rates in Cells F14:F21 under the labels “Range” and “Rate.” The Minimum LTL Charge (Cell F14) serves as a floor on the freight charge assessed by the LTL carrier, in this case a flat charge of $367.79. The next range labeled “1” corresponds to 1 – 499.99 pounds. The freight rate for this range is $234.46/CWT, where CWT corresponds to century weight (hundreds of pounds). The remaining ranges correspond to 500 – 999.99 pounds, 1,000 – 1,999.99 pounds, 2,000 – 4,999.99 pounds, 5,000 – 9,999.99 pounds, 10,000 – 19,999.99 pounds, and 20,000+ pounds. Directly below the 20,000+ pounds range is the LTL Discount (Cell F22) negotiated between the customer and ABF. The LTL Discount must be applied to the nominal LTL freight rates in Cells F14:F21. The LTL Fuel Surcharge (Cell F23) is a fixed percentage added to the LTL freight charge to offset the cost of rising diesel prices. The LTL freight charge is: (a) the linehaul rate (based on dividing the shipment weight by 100 and then multiplying by the $/CWT) plus (b) the LTL Fuel Surcharge (the linehaul rate multiplied by the LTL Fuel Surcharge %).

The LTL rates also must account for the practice of over-declaring a shipment at the next weight-break range. This over-declared weight is based on looking at the next highest LTL weight-break range only. It can be shown algebraically that every LTL weight-break range, except for the last weight-break range of 20,000+ pounds, always will have some weight at which it becomes less expensive to over-declare the shipment at the minimum weight and corresponding freight rate of the next weight-break range. For example, if the shipment weight fell within 500 – 999.99 pounds (rate = $196.36/CWT), it would be less expensive to label the shipment weight, for example, as follows: 990 pounds as 1,000 pounds @ $164.00/CWT). LTL carriers will allow the shipment to be artificially increased if doing so saves the customer money. The benefit to the LTL carrier is that customers list true weights on the bill of lading, which allows the LTL carrier to avoid having to weigh every shipment.

TL freight rate data are listed below the LTL freight rate data. The fuel surcharge for the TL carrier must be entered in Cell F26. Notice that TL Fuel Surcharge is stated in $/mile. The TL Rate/Mile (Cell F27) must be negotiated by the TL carrier and the party paying the freight (the customer in this example). The Miles (Cell F28) were obtained from ABF's software. The Minimum TL Charge (Cell F29) serves as a floor on what the TL carrier will charge. In general, the freight rate per CWT, per pound, and per unit decrease at a decreasing rate as shipment weight increases (economies of weight). The TL freight charge is competitive compared to the LTL freight charges beyond 10,000 pounds (and sometimes even at lower weights). Therefore, we always must check to determine if an LTL shipment should ship with the TL carrier, i.e., over-declared as a TL. Before this problem can be modeled using Excel Solver, some other calculations are necessary to calculate the actual freight rates. Actual freight rates must account for the following: LTL Discount, LTL and TL Fuel Surcharges, the weights over which the Minimum LTL Charge applies, the LTL over-declared weights, and the TL over-declared weights. Table 2 from the Excel spreadsheet includes most of these: LTL Discount, LTL and TL Fuel Surcharges, weights over which the Minimum LTL Charge applies, and the LTL over-declared weights. The TL over-declared weight is addressed later in this paper.

Cell C36 in Table 2 applies the LTL Discount and the LTL Fuel Surcharge to the Minimum LTL Charge as follows: =(F14*(1-F$22))*(1+F$23), where Cell F14 corresponds to the nominal Minimum LTL Charge, Cell F22 corresponds to the LTL Discount, and Cell F23 corresponds to the LTL Fuel Surcharge %. For the LTL weight range of 1 – 499.99 pounds (Cell C37), the LTL Discount and the LTL Fuel Surcharge % are applied as follows: =(F15*(1-F$22))*(1+F$23). The formulas for all LTL weight ranges are as follows:

Cell C36: =(F14*(1-F$22))*(1+F$23)
Cell C37: =(F15*(1-F$22))*(1+F$23).
Cell C38: =(F16*(1-F$22))*(1+F$23)
Cell C39: =(F17*(1-F$22))*(1+F$23)
Cell C40: =(F18*(1-F$22))*(1+F$23)
Cell C41: =(F19*(1-F$22))*(1+F$23)
Cell C42: =(F20*(1-F$22))*(1+F$23)
Cell C43: =(F21*(1-F$22))*(1+F$23)

The TL Charge (Cell C44) equals the maximum of two charges: the Minimum TL Charge and the applicable TL charge, which is calculated as [(TL Fuel Surcharge/Mile + TL Rate/Mile) * Miles]. The formula in Cell C44 is =MAX(F29,((F26+F27)*F28)). In Cells E36:E42 are the "Weight Breakpoints." Cell E36 determines the Weight Breakpoint (indifference point) between the Minimum LTL Charge ($191.99) and the freight rate of $122.39/CWT for the range of 1 – 499.99 pounds. The weight breakpoint is calculated as $191.99 = $122.39X. Then, solving for X provides 1.5687 CWT (156.87 CWT * 100 = 156.87 pounds). Therefore, the Minimum LTL Charge applies for weights between 1 – 156.86 pounds. For the range of 1 – 499.99 pounds ($122.30/CWT), we must first determine the weight at which we will over-declare a shipment as 500 pounds @ $102.50/CWT. This over-declared weight is calculated as \$122.39X = 500 * \$102.50, or \$122.39X = \$512.50. Then, solving for X provides 418.74 pounds.

Table 2: Freight Rates after Applying LTL Discount & Surcharges

	B	C	D	E	F
35	**Weight (pounds)**	**Actual Rate***		**Weight Breakpoints**	
36	Min. LTL Charge	\$191.99		156.87	Weight up to which Min. LTL applies
37	1	\$122.39	per cwt	418.74	Weight at which to over-declare to next LTL range
38	500	\$102.50	per cwt	835.22	Weight at which to over-declare to next LTL range
39	1,000	\$85.61	per cwt	1,774.33	Weight at which to over-declare to next LTL range
40	2,000	\$75.95	per cwt	3,982.23	Weight at which to over-declare to next LTL range
41	5,000	\$60.49	per cwt	8,999.83	Weight at which to over-declare to next LTL range
42	10,000	\$54.44	per cwt	18,001.47	Weight at which to over-declare to next LTL range
43	20,000	\$49.00	per cwt		
44	**TL Charge**	\$1,463.49			

This table applies the LTL discount and the LTL and TL fuel surcharges. In addition, weight breakpoints are determined for which the Minimum LTL charge applies and for the LTL over-declared weights.

Therefore, the freight rate for 156.87 pounds – 418.73 pounds will equal \$122.39/CWT, and the freight rate for 418.74 pounds – 499.99 pounds will equal a flat charge of \$512.50. The remaining LTL over-declared weights are calculated similarly. The formulas for all the Weight Breakpoints are as Follows. Note: Students could confirm all of these Weight Breakpoints using Q-Rate for Windows ®.

Cell E36: =(C36/C37)*100
Cell E37: =(B38*C38)/C37
Cell E38: =(B39*C39)/C38
Cell E39: =(B40*C40)/C39
Cell E40: =(B41*C41)/C40
Cell E41: =(B42*C42)/C41
Cell E42: =(B43*C43)/C42

Table 3 displays the restructured tariff of all freight rates after building in the over-declared weight ranges. The values in Cells B54:B67 correspond to the beginning of each LTL weight-break range. Cells C54:C67 contain the relevant freight rates for each LTL weight-break range using the following formulas. Note: Cell C68 contains the TL charge.

Cell C54: =C36
Cell C55: =C37
Cell C56: =B38/100*C38
Cell C57: =C38
Cell C58: =B39/100*C39
Cell C59: =C39
Cell C60: =B40/100*C40
Cell C61: =C40
Cell C62: =B41/100*C41

Cell C63: =C41
Cell C64: =B42/100*C42
Cell C65: =C42
Cell C66: =B43/100*C43
Cell C67: =C43
Cell C68: =C44

Table 3: Actual Freights with Over-Declared Weight Ranges Added

	B	C	D	E	F	G
53	**Weight (pounds)**	**Actual Rate**				**Formula**
54	1	$191.99	Minimum LTL flat charge			=C54
55	156.87	$122.39	per cwt			=K$10/100*C55
56	418.74	$512.50	flat charge (over-declared to next LTL breakpoint)			=C56
57	500	$102.50	per cwt			=K$10/100*C57
58	835.22	$856.10	flat charge (over-declared to next LTL breakpoint)			=C58
59	1,000	$85.61	per cwt			=K$10/100*C59
60	1,774.33	$1,519.00	flat charge (over-declared to next LTL breakpoint)			=C60
61	2,000	$75.95	per cwt			=K$10/100*C61
62	3,982.23	$3,024.50	flat charge (over-declared to next LTL breakpoint)			=C62
63	5,000	$60.49	per cwt			=K$10/100*C63
64	8,999.83	$5,444.00	flat charge (over-declared to next LTL breakpoint)			=C64
65	10,000	$54.44	per cwt			=K$10/100*C65
66	18,001.47	$9,800.00	flat charge (over-declared to next LTL breakpoint)			=C66
67	20,000	$49.00	per cwt			=K$10/100*C67
68	**TL Charge**	$1,463.49	flat charge			=C68

This table shows the weight-break ranges, the actual LTL and TL freight rates, and the formulas for calculating freight rates based on the shipment weight.

As shown in Table 3, for the first weight range of 1 – 156.86 pounds, the Minimum LTL Charge ($191.99) applies. For 156.87 – 418.73 pounds, the LTL freight rate is equal to the Shipment Weight (listed in Cell K10)/100 * $122.39/CWT. For 418.74 – 499.99 pounds, the LTL freight rate is $512.50 (the weights in this range are over-declared as 500 pounds @ $102.50/CWT). For 500 – 835.21 pounds, the LTL freight rate is equal to the Shipment Weight/100 * $102.50/CWT. For 835.22 – 999.99 pounds, the LTL freight rate is $856.10 (these weights are over-declared as 1,000 pounds @ $85.61/CWT). For 1,000 – 1,774.32 pounds, the LTL freight rate is equal to the Shipment Weight/100 * $85.61/CWT. For 1,774.33 – 1,999.99 pounds, the LTL freight rate is $1,519.00 (these weights are over-declared as 2,000 pounds @ $75.95/CWT). For 2,000 – 3,982.22 pounds, the LTL freight rate is equal to the Shipment Weight/100 * $75.95/CWT. For 3,982.23 – 4,999.99 pounds, the LTL freight rate is $3,024.50 (these weights are over-declared as 5,000 pounds @ $60.49/CWT). For 5,000 – 8,999.82 pounds, the LTL freight rate is equal to the Shipment Weight/100 * $60.49/CWT. For 8,999.83 – 9,999.99 pounds, the LTL freight rate is $5,444.00 (these weights are over-declared as 10,000 pounds @ $54.44/CWT). For 10,000 – 18,001.46 pounds, the LTL freight rate is equal to the Shipment Weight/100 * $54.44/CWT. For 18,001.47 – 19,999.99 pounds, the LTL freight rate is $9,800.00 (these weights are over-declared as 20,000 pounds @ $49.00/CWT). For 20,000+ pounds, the LTL freight rate is equal to the Shipment Weight/100 * $49.00/CWT. Cells B54:G67 form an Excel table array (LTLFreightRate) that will be used in another part of the spreadsheet to determine the relevant LTL freight charge. The TL Charge is $1,463.49 (shown in Cell G68).

Model

The format of the inventory-theoretic model is based on the model described by Swenseth and Godfrey (2002). Annual Logistics Cost = Annual Order Cost + Annual In-Transit Holding Cost + Annual Warehouse Holding Cost + Annual Purchase Cost + Annual Transportation Cost. Annual Logistics Cost (L) is represented as:

$$L = \frac{RS}{Q} + C_v f_i Rt + \left[C_v + C_s\right]\frac{f_w Q}{2} + RC_v + RC_s \tag{1}$$

R = annual requirements or demand in units; S = cost to place an order; Q = order quantity in units; C_v = unit cost from the vendor (determined from the all-units purchase quantity discount schedule); f_i = in-transit holding cost fraction (rate); t = transit time (fraction of a year); C_s = shipping (transportation) cost per unit; f_w = warehouse holding cost fraction (rate).These costs are built into the spreadsheet as shown in Table 4 in the Appendix. Table 4 shows the following. Cell J10 is the Order Quantity, which is used as the "Changing Variable" cell in the Excel Solver model. Cell K10 (Shipment Weight) is equal to the Order Quantity * Unit Weight. Cell L10 returns the Relevant LTL Freight Rate based on performing a table lookup (using Shipment Weight) of Cells B54:G67 in the table array, "LTLFreightRate." Cell M10 is the TL Freight Rate. Cell N10 is the Applicable Freight Rate (the lower of the Relevant LTL Rate and the TL Freight Rate). Cell O10 determines the Freight Rate per Unit. Cell P10 is based on a table lookup (using Order Quantity) of the Unit Costs in the table array, "UnitCostLookup," in Cells E8:F11. Cell Q10 is used to calculate the Annual Order Cost. Cell R10 is used to calculate the Annual In-Transit Holding Cost (note: the transit time is dependent on whether the LTL or the TL carrier is used). Cell S10 is used to calculate the Annual Transport Cost. Cell T10 is used to calculate the Annual Warehouse Holding Cost. Cell U10 is used to calculate the Annual Purchase Cost. Annual Logistics Cost is calculated in Cell V10, which serves as the "Set Objective" cell in the Solver model. Cells K12:K15 are used to create the constraints in the Solver model. The Cube Used (Cell K12) equals Order Quantity * Unit Cube.

The Max. TL Cube (3,936) is given in Cell K13. The Weight Used (Cell K14) simply references Shipment Weight. The Max. Weight (Cell K15) is 46,100 pounds. All formulas for this part of the spreadsheet are provided in the Appendix. We now need to add three constraints: K12 ≤ K13, K14 ≤ K15, and J10 = integer. Note: Before running the Solver model, it is important to enter some positive value in Cell J10; otherwise, Solver will return an error message. Next, we solve the model in Solver using the GRG Nonlinear Solver.

RESULTS AND DISCUSSIONS

Results Of Excel Solver Model

The results for the Excel Solver model are displayed in Table 4 in the Appendix. The Order Quantity that minimizes Annual Logistics Cost is 345 units, with a Shipment Weight of 13,800 pounds and Annual Logistics Cost of $1,021,041. The TL carrier will be used (note the Applicable Freight Rate corresponds to the TL Freight Rate). The Unit Cost is $194.90 (345 units falls in the range of 300 – 599.99 units). At this point, the instructor might want to require students to experiment with different quantities to analyze what happens to each of the annual costs as the Order Quantity increases. For example, the instructor could have students find Annual Logistics Cost for the purchase quantity breakpoints of 300 and 600 units. In addition, students could calculate Annual Logistics Cost at each of the weight breakpoints by converting the weights of 500, 1,000, 2,000, 5,000, 10,000, and 20,000 pounds to their corresponding order quantities by dividing each of these weights by unit weight. Alternatively, the instructor could require students to enumerate all possible order quantities and their respective costs in the spreadsheet (in the cells below Table 4).

Assessing Effectiveness Of This Approach

To test the effectiveness of this approach, the instructor could randomly divide students into two groups: Group 1 would be the control group (no exposure to the ABF's Q-Rate for Windows ® and Excel Solver software) while Group B would use both types of software. Then, the instructor could measure performance on exam problems related to calculating freight rates and inventory-theoretic model costs. Finally, the instructor could test for a significance difference between the mean scores on these problems.

CONCLUSION

In conclusion, the goal of this paper was to present an exercise helps students learn the following concepts: how to look up LTL truckload freight rates using software provided by an LTL carrier (ABF); how to calculate LTL and TL freight rates, including how to apply minimum charges, less-than-truckload discounts, and fuel surcharges; to decide whether to over-declare LTL shipments; and how to modify the basic Economic Order Quantity (EOQ) model to find the purchase lot size that minimizes annual logistics cost. We presented two tools to be used in the exercise—software for obtaining actual LTL motor carrier freight rates and Excel Solver. The primary finding in this paper was the development of an exercise for teaching Supply Chain Management students how to calculate motor carrier freight rates and the annual costs in the inventory-theoretic model. The primary limitation of the exercise presented here is the time required to discuss both tools used in this exercise. The instructor previously has devoted a 3-hour class to discuss this exercise. Future research related to this exercise will include creation of an inventory-theoretic model applied to multiple products sourced from the same supplier and from multiple suppliers using a milk run.

APPENDIX

Table 4: Excel Solver Setup

	J	K	L	M	N	O
6						
7			Relevant	TL	Applicable	Freight
8	Order	Shipment	LTL	Freight	Freight	Rate
9	Quantity	Weight	Rate	Rate	Rate	per Unit
10	345	13,800.00	$7,512.72	$1,463.49	$1,463.49	$4.24
11						
12	Cube Used	1,553				
13	Max. TL Cube	**3,936**				
14	Weight Used	13,800				
15	Max. Weight	**46,100**				

	P	Q	R	S	T	U	V
6			Annual		Annual		
7		Annual	In-Transit	Annual	Warehouse	Annual	Annual
8	Unit	Order	Holding	Transport	Holding	Purchase	Logistics
9	Cost	Cost	Cost	Cost	Cost	Cost	Cost
10	$194.90	$609	$2,403	$21,200	$22,329	$974,500	$1,021,041

Cell Formulas:

Cell K10: =C16*J10
Cell L10: =VLOOKUP(K10,LTLFreightRate,6)
Cell M10: =G68

Cell N10: =MIN(L10:M10)
Cell O10: =N10/J10
Cell P10: =VLOOKUP(J10,UnitCostLookup,2)
Cell Q10: =(C12/J10)*C14
Cell R10: =IF(N10=G68,P10*C23/365*C10*C12,P10*C22/365*C10*C12)
Cell S10: =C12*O10
Cell T10: =(P10+O10)*C7*(J10/2)
Cell U10: =P10*C12
Cell V10: =SUM(Q10:U10)
Cell K12: =J10*C17
Cell K13: =C27
Cell K14: =K10
Cell K15: =C25

REFERENCES

ABF Freight Systems, Inc. (2012). *Q-Rate Download*. Retrieved February 26, 2012 from the ABF, Inc. web site: http://www.abfs.com/ecommerce/qfamily/qrate/qratedownload.asp

Ballou, R.H. (1991) "The Accuracy in Estimating Truck Class Rates for Logistical Planning," *Transportation Research-A*, vol. 25A(6), p. 327-337.

Baumol, W.J. and H.D. Vinod (1970) "An Inventory Theoretic Model of Freight Transport Demand," *Management Science*, vol. 16(7), p. 413-421.

Blumenfeld, D.E., L.D. Burns, C.F. Daganzo, M.C., Frick, and R.W. Hall (1987) "Reducing Logistics Costs at General Motors," *Interfaces*, vol. 17(1), p. 26-47.

Buffa, F.P. (1987) "Transit Time and Cost Factors: Their Effects on Inbound Consolidation," *Transportation Journal*, vol. 27(1), p. 50-62.

Buffa, F.P. (1988) "Inbound Consolidation Strategy: The Effect of Inventory Cost Rate Changes," *International Journal of Physical Distribution & Materials Management*, vol. 18(7), p. 3-14.

Burwell, T.H., D.S. Dave, K.E. Fitzpatrick, and M.R. Roy (1997) "Economic Lot Size Model for Price Dependent Demand under Quantity and Freight Discounts," *International Journal of Production Economics*, vol. 48(2), p. 141-155.

Carter, J.R. and B.G. Ferrin (1996) "Transportation Costs and Inventory Management: Why Transportation Costs Matter," *Production and Inventory Management Journal*, vol. 37(3), p. 58-62.

Gaither, N. (1982) "Using Computer Simulation to Develop Optimal Inventory Policies," *Simulation*, vol. 39(3), p. 81-87.

He, W., Y. Hu, and L. Guo (2010) "Model and Algorithm of JIT Purchase Based on Actual Freight Rate," *Applied Mechanics and Materials*, vols. 37-38, p. 675-678.

Higginson, J.K. (1993) "Modeling Shipper Costs in Physical Distribution Analysis," T*ransportation Research-A*, vol. 27A(2), p. 113-124.

Hwan, H., D.H. Moon, and S.W. Shin (1990) "An EOQ Model with Quantity Discounts for both Purchasing Price and Freight Costs," *Computers & Operations Research*, vol. 17(1), p. 73-78.

Kay, M.G. and D.R. Warsing (2009) "Estimating LTL Rates Using Publicly Available Empirical Data," *International Journal of Logistics: Research and Applications*, vol. 12(3), p. 165-193.

Langley, J.C. (1980) "The Inclusion of Transportation Costs in Inventory Models: Some Considerations," *Journal of Business Logistics*, vol. 2(1), p. 106-125.

Larson, P.D. (1988) "The Economic Transportation Quantity," *Transportation Journal*, vol. 28(2), p. 43-48.

Lee, C. (1986) "The Economic Order Quantity for Freight Discount Costs," *IIE Transactions*, vol. 18(3), p. 318-320.

Madadi, A., M.E. Kurz, and J. Ashayeri (2010) "Multi-Level Inventory Management Decisions with Transportation Cost Consideration," *Transportation Research Part E*, vol. 46(5), p. 719-734.

Mendoza, A. and J.A. Ventura (2008) "Incorporating Quantity Discounts to the EOQ Model with Transportation Costs," *International Journal of Production Economics*, vol. 113(2), p. 754-765.

Mendoza, A. and J.A. Ventura (2009) "Estimating Freight Rates in Inventory Replenishment and Supplier Selection Decisions," *Logistics Research*, vol. 1(3-4), p. 185-196.

Ramasesh, R.V. (1993) "A Logistics-Based Inventory Model for JIT Procurement," *International Journal of Operations & Production Management*, vol. 13(6), p. 44-58.

Russell, R.M. and L.J. Krajewski (1991) "Optimal Purchase and Transportation Cost Lot Sizing for a Single Item," *Decision Sciences*, vol. 22(4), p. 940-951.

Sheffi, Y., B. Eskandari, and H.N. Koutsopoulos (1988) "Transportation Mode Choice Based on Total Logistics Costs," *Journal of Business Logistics*, vol. 9(2), p. 137-154.

Swenseth, S.R. and F.P. Buffa (1990) "Just-in-Time: Some Effects on the Logistics Function," *The International Journal of Logistics Management*, vol. 1(2), p. 25-34.

Swenseth, S.R. and F.P. Buffa (1991) "Implications of Inbound Lead Time Variability for Just-in-Time Manufacturing," *International Journal of Operations & Production Management*, vol. 11(7), p. 37-48.

Swenseth, S.R. and M.R. Godfrey (1996) "Estimating Freight Rates for Logistics Decisions," *Journal of Business Logistics*, vol. 17(1), p. 213-231.

Swenseth, S.R. and M.R. Godfrey (2002) "Incorporating Transportation Costs into Inventory Replenishment Decisions," *International Journal of Production Economics*, vol. 77(2), p. 113-130.

Tersine, R.J. and S. Barman (1991) "Lot Size Optimization with Quantity and Freight Rate Discounts," *Logistics and Transportation Review*, vol. 27(4), p. 319-332.

Tersine, R.J., P.D. Larson, and S. Barman (1989) "An Economic Inventory/Transport Model with Freight Rate Discounts," *Logistics and Transportation Review*, vol. 25(4), p. 291-306.

Tyworth, J.E. (1991) "The Inventory Theoretic Approach in Transportation Selection Models: A Critical Review," *Logistics and Transportation Review*, vol. 27(4), p. 299-318.

Tyworth, J.E. (1991) "Transport Selection: Computer Modelling in a Spreadsheet Environment," *International Journal of Physical Distribution & Logistics Management*, vol. 21(7), p. 28-36.

Wehrman, J.C. (1984) "Evaluating the Total Cost of a Purchase Decision," *Production and Inventory Management*, vol. 25(4), p. 86-90.

Yildirmaz, C., S. Karabati, and S. Sayin (2009) "Pricing and Lot-Sizing Decisions in a Two-Echelon System with Transportation Costs," *OR Spectrum*, vol. 31(3), p. 629-650.

BIOGRAPHY

Dr. Godfrey earned his B.S. in Operations Management and M.S. in Management Information Systems from Northern Illinois University, and his Ph.D. in Production & Operations Management from the University of Nebraska - Lincoln. He is department chair of the Marketing and Supply Chain Management Department at UW Oshkosh. He is a CFPIM, CIRM, and CSCP through APICS and a CPSM through ISM. Email: godfrey@uwosh.edu

Dr. Manikas earned his B.S. in Computer Science and M.B.A. in Materials and Logistics Management from Michigan State University, and his Ph.D. from The Georgia Institute of Technology. Prior to that, he was an instructor for supply chain optimization courses for i2 Technologies and worked as a management consultant for KPMG Peat Marwick, CSC, and Deloitte Consulting. Dr. Manikas is an Assistant Professor in the Marketing and Supply Chain Management Department at UW Oshkosh. Email: manikasa@uwosh.edu